ECONOMY ASPECT FOR NUCLEAR DESALINATION SELECTION IN MURIA PENINSULA

Sudi Ariyanto and Siti Alimah
Center for Nuclear Energy Development (PPEN) BATAN
Jl. Kuningan Barat, Mampang Prapatan Jakarta 12710
Phone/ Fax : (021) 5204243 Email: asudi@batan.go.id

ABSTRACT

ECONOMY ASPECT FOR NUCLEAR DESALINATION SELECTION IN MURIA PENINSULA. *An assessment of economy aspect for nuclear desalination selection has been carried out. This study compares the costs of water production for the Multi Stage Flash Distillation (MSF), Multi Effect Distillation (MED) and Reverse Osmosis (RO) desalination process coupled to PWR. Economic analysis of water cost are performed using the DEEP-3.1. The results of the performed case study of Muria Peninsula showed that the water cost to desalination process coupled with PWR nuclear power plant (at 5% interest rate, 2750 m^3/day capacity, 28^{o}C temperature, 28.700 ppm TDS) with MSF plant is the highest (1.353 \$/m^3), compared to 0.885 \$/m^3 and 0.791 \$/m^3 with the MED and RO plants respectively. As for MSF process, water cost by RO are also sensitive to variables, such as the interest rate, temperature and total salinity. However, MED process is sensitive to interest rate and temperature based on the economic aspect. MSF and MED plants produce a high-quality product water with a range of 1.0 – 50 ppm TDS, while RO plants produce product water of 200 – 500 ppm TDS. Water requirements for reactor coolant system in PWR type is about 1 ppm. Based on economic aspect and water requirements for reactor coolant system in PWR type, so co-generation of PWR and MED may be a favourable option for being applied in Muria Peninsula.*

Key Words: Desalination, RO, MSF, MED, Coupling, Nuclear Power Plant, Economic.

ABSTRAK

ASPEK EKONOMI PADA PEMILIHAN DESALINASI NUKLIR DI SEMENANJUNG MURIA. *Kajian aspek ekonomi pada pemilihan desalinasi nuklir telah dilakukan. Studi ini membandingkan biaya produksi air proses desalinasi Multi Stage Flash Distillation (MSF), Multi Effect Distillation (MED) and Reverse Osmosis (RO), yang dikopel dengan PWR. Analisis ekonomi biaya produksi air dilakukan menggunakan DEEP-3.1. Hasil studi kasus yang telah dilakukan di wilayah Semenanjung Muria memperlihatkan bahwa biaya produksi air untuk proses desalinasi yang dikopel dengan PLTN jenis PWR (pada interest rate 5%, kapasitas 2750 m^3/hari, suhu 28^{o}C, TDS 28.700 ppm) untuk instalasi MSF adalah paling tinggi (1,353\$/m^3) dibanding instalasi MED (0,885 \$/m^3) dan RO (0,791 \$/m^3). Sebagaimana proses MSF, biaya produksi air RO juga sensitif terhadap variabel, seperti interest rate, suhu dan total salinitas. Namun, proses MED hanya sensitif terhadap interest rate dan suhu. Instalasi MSF dan MED menghasilkan air produk dengan kualitas tinggi dengan kisaran TDS 1-50 ppm, sedangkan RO menghasilkan air produk dengan TDS 200-500 ppm. Persyaratan air untuk sistem pendingin reaktor jenis PWR adalah sekitar 1 ppm. Berdasarkan aspek ekonomi dan persyaratan air untuk sistem pendingin reaktor PWR, maka kogenerasi PWR dan MED dapat menjadi pilihan yang tepat untuk diaplikasikan di Semenanjung Muria.*

Kata Kunci : Desalinasi, RO, MSF, MED, kopel, PLTN, Ekonomi.

1. INTRODUCTION

There is a plan to introduce nuclear power plants (NPP) into Java-Madura electricity grid. A comprehensive study on different energy sources shows that NPP is economically and technically viable to be introduced into the grid in 2016/2017[1]. Furthermore, in a document issued by the Government, NPP is included to be a part of the national energy mix. According to the document, nuclear share in the energy mix is projected about 4% by 2025[2]. The candidate site is Muria Peninsula in Central Java.

There is a concept of NPP utilization for co-generation purposes, i.e. for electricity generation as well as desalination, hydrogen production, coal liquefaction/gasification, etc. This paper is dealing with nuclear desalination to produce electricity and fresh water as well. Fresh water produced in the desalination unit may be used to supply water coolant for primary system and secondary system of the NPP unit, domestic water or process water. Desalination is a process to remove dissolved minerals from seawater or brackish water and produce fresh water. Total of desalination water product of one NPP with 1000 MWe power is approximately 2750 m^3/day[3].

This study is done to explore any possibility to utilize co-generation concept of desalination. A PWR of 1000 MWe is coupled with a desalination plant of MSF (*Multi-Stage Flash Distillation*), MED (*Multi-Effect Distillation*) and RO (*Reverse Osmosis*). A DEEP-3.1 program that's issued by the IAEA, , is used as a tool for analysis. A comparison of cost for producing water is performed using variables of interest rate, sea water temperature and TDS (Total Dissolved Solid). The objective of the economic evaluation is to help the decision-maker to eventually implement an integrated nuclear desalination plant, generating both electricity and fresh water.

2. DESALINATION TECHNOLOGY AND ECONOMIC ASPECTS

2.1. Desalination Technology

Most common technologies to be coupled with nuclear reactors are thermal processes and mechanical processes. Thermal processes includes MSF or MED, while mechanical processes includes RO. Each process has its own advantages and limitations, as follows[4] :

a. Advantages of thermal distillation processes:
- High reliability.
- Minimal pre-treatment requirements for feed sea-water.
- Capability to exploit low enthalpy waste heat from power plants.
- Economical: a cheap heat source is available from NPP.

b. Disadvantages of thermal distillation :
- Amount of water production depends on operating temperature.
- Tube scaling, which occurs at high temperatures by $CaSO_4$. This introduces a limit to the top brine temperature (of 120°C), and consequently to the efficiency.
- The energy consumption of these processes is quite high and depends mainly on the temperature and gained output ratio (GOR).

c. Advantages of Reverse Osmosis:
- Relatively low final energy consumption.
- Smaller and more compact.
- Lower investment.

d. Disadvantages of Reverse Osmosis:
- The sensitivity of membranes to fouling.
- Lower water quality compared to that of thermal distillation.
- Need for expensive pre-treatment (feed water must pass through very narrow passages, suspended solids must be removed).
- Needs expensive electricity as main drive power.
- High maintenance requirements.
- High operating costs

Thermal distillation plants produce a high-quality product water with a range of 1.0 – 50 ppm TDS, while RO plants produce product water of 200 – 500 ppm TDS.

The choice of desalination technology determines the manner in which the desalination plant is coupled with the reactor. With the distillation processes as MSF and MED, the coupling between the desalination plant and the reactor is primarily thermal, although some electrical

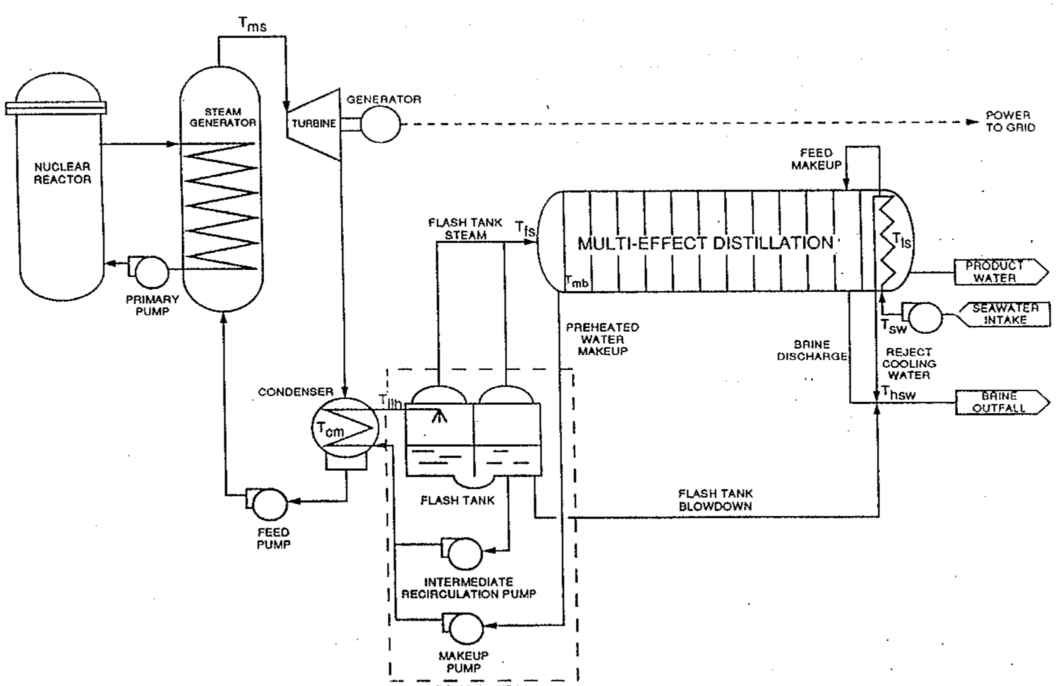

Figure 1. Scheme of Coupling Between MED Desalination Plant and Nuclear Reactor[5]

energy is required for the operation of pumps for the system. As example, scheme of coupling between MED desalination plant and nuclear reactor is shown in Figure 1. The thermal coupling may take the form of steam extraction, for example from the cross-over from high pressure to low pressure turbines. In this latter case, the need to provide thermal conditions that satisfy the requirements for the desalination process may impose special design requirements or constraints on the turbine. The two main steam cycles considered nowadays for coupling with a nuclear reactor are backpressure turbine and extracting turbine. The selection of power plant and desalination plant combinations for co-generation (simultaneous production of power and water) depends on several factors, of which the most important one is the water-to-power ratio (W/P), defined as the ratio of the total water production capacity (m^3/day), and the MW(e) of the power produced. The choice of the turbine coupling to the desalination plant should be assessed in view of the real local W/P ratio. Typical W/P ratios for various combinations are given in Table 2.

Table 2. Typical W/P Ratios for Turbine Scheme with MED, MSF and RO Plants[6]

Technology	W/P m^3/day/MWe
Backpressure steam turbine + MED	1140
Backpressure steam turbine + MSF	800
Extraction steam turbine + MED	570
Extraction steam turbine + MSF	400
RO (using electric power only)	2700-5000

In the thermal coupling, intermediate loops may be included to provide isolation of the reactor from the desalination plant. Reverse osmosis systems may be contiguous systems. With contiguous RO, the desalination system will share some common facilities or systems with the reactor plant (e.g. seawater intake and outfall structures), however the only energetic coupling required is electrical.

2.2. Economic Aspects

Economic is an important aspect to be done before the decision making to desalination desalination technology. Cost for producing water is evaluated based on all related costs such as capital cost, energy cost, and O&M cost. The capital cost includes the purchase cost of major equipment, auxiliary equipment, land, construction, management overheads, contingency costs etc. The capital costs for seawater desalination plants have decreased over the years due to the ongoing development of processes, components and materials[7]. The energy costs play a dominant role for thermal processes. Distillation costs will fluctuate more than RO with changing energy costs. O&M cost includes labor, chemicals, consumables and spare parts.

In general, water production cost is affected by required distillate capacity, site characteristics, and feed water quality. The desalted water cost is reduced as required distillate capacity is increased, even though large capacity plants require high initial investment, larger sizes of treatment units, pumps, water storage tanks and water distribution systems. Site characteristics may be a factor influencing pumping costs and the costs of pipe installations. Yet another factor influencing land cost could be the local regulatory requirements and the costs associated with the acquisition of permits etc. The lower the salinity (TDS) of the feed-water, the lower would be the energy consumption of the system. Low TDS would also lead to high conversion rates and less dosing of antiscalant chemicals.

2.3. Methodology

This assessment is implemented by using DEEP-3.1. Methodology of DEEP-3.1 is summarized as follows :

a. Selection of thermodinamic scheme reflecting coupling configuration between energy source with desalination process. In this program, there are several option of energy source as follows:
    - Nuclear with steam turbine, gas turbine or nuclear heat.
    - Fossil with coal steam cycle, oil steam cycle, gas turbine, combined cycle or fossil heat.

- Renewable heat.

In this study, nuclear energy source with steam turbine is selected.

b. Determination of parameters:
   - General parameters: required capacity (m^3/day), sea water salinity (ppm), interest rate (%), sea water feed temperature (^oC), purchased electricity cost ($/kWh).
   - NPP related parameters: thermal power (MWt), electric power (MWe), NPP fuel cost ($/MWh) and NPP construction cost ($/kW).
   - Distillation plant related parameters for MSF and MED: brine maximum temperature (^oC), heating steam temperature (^oC) and MSF/MED construction cost ($/$m^3$/day),
   - Distillation plant related parameters for RO: energy recovery fraction (%), recovery ratio (%), design flux (l/m^2.hour) and desalination plant construction cost ($/$m^3$/hari).

c. Data input and computer program running.

In this studi, option for turbine scheme is set as extraction and backpressure. Options for specific carbon tax, thermal steam compression and backup heat are not used. The main assumptions used in DEEP-3.1 calculations are presented in Table 1.

Table 1. Calculation Base for the MSF, MED AND RO Plants

Parameter	MSF	MED	RO
Base year	2009	2009	2009
Interest rate, (%)	5	5	5
Life time of water plant, (Years)	20	20	20
Initial year of operation	2017	2017	2017
Year of construction	2011	2011	2011
Currency	$	$	$
Purchased electricity cost ($/Kwh)	0,04	0,04	0,04
Seawater salinity, (ppm)	28700	28700	28700
Seawater temperature (°C)	28	28	28
Construction cost of water plant ($/m3/day)	1200	900	700

3. DISCUSSION

The modified and updated software DEEP-3.1 is selected as the methodology to be used for the calculation of water production cost in the case study. The capital investment, operating & maintenance (O&M) cost are included in this evaluation. Analysis is performed based on the input data as the following. The TDS is set as 28.700 ppm and sea water temperature 28^oC. Construction cost for NPP is assumed to be 2600 $/kW[8], production capacity 2.750 m^3/d, interest rate 5%, construction cost for MSF 1200 $/$m^3$/d, MED 900 $/$m^3$/d and RO 700 $/$m^3$/d[9], ratio of recovery RO 45%, top brine temperature for MED 65^oC and MSF 110^oC, base year 2009, year of construction 2011, initial year of operation 2017 and currency $. Table 3 shows capital cost, O&M cost and water cost for MED, MSF and RO obtained by DEEP 3.1.

Table 3. Capital Cost, O &M Cost, Water Cost of MSF, MED and RO Processes

Parameter	MSF	MED	RO
Capital Cost ($/m^3)	0.483	0.366	0.217
O&M (($/m^3)	0.114	0.119	0.453
Water cost ($/ m^3)	1.353	0.885	0.788

Capital cost for MSF is the highest among others, while capital cost for RO is the smallest. For O&M cost, the value of RO is the highest due to the fact that RO process is sensitive to the fouling than MED and MSF. A sensitivity analysis is done to see the effect of interest rate. In this study, the interest rate is varied from 5% to 10%. The results can be seen in Table 4.

Table 4. Interest Rate Effect to Water Cost of MSF, MED and RO Processes

Installation	Water Cost ($/m^3)		
	IR 5%	IR 8%	IR 10%
MSF	1.353	1.407	1.445
MED	0.885	0.918	0.941
RO	0.788	0.796	0.802

As is general for any other economic activities, the increase in interest rate will also increase the production cost. The table shows also that co-generation installation using PWR and RO produces cheapest cost for any value of interest rate. When the interest rate increases of 8% to 10%, then the water cost will also increase about 2.7% for MSF, 2.5% for MED and 0.7% for RO. If the interest rate increases of 5% to 8%, then the cost will also increase about 4% for MSF, 3.7% for MED and 1.0% for RO.

Analysis is also performed by varying seawater temperature as well as TDS. The results are shown in Table 5 for each installation.

Table 5. Water Cost of MED, MSF and RO with Temperature and TDS Variables

TDS (ppm)	Temperature (^{o}C)	Water Cost ($/m^3)		
		MSF	MED	RO
28000	27	1.337	0.859	0.788
	29	1.352	0.885	0.786
	31	1.369	0.917	0.784
30000	27	1.339	0.859	0.793
	29	1.354	0.885	0.790
	31	1.371	0.917	0.788
32000	27	1.341	0.859	0.798
	29	1.357	0.885	0.795
	31	1.374	0.917	0.793

Table 5 shows the effect of TDS and temperature on the water cost for installation of PWR+MED, PWR+MSF and PWR+RO coupling. The PWR+MED coupling can be seen from the table that an increase of TDS at the same seawater temperature have no effect on the water cost.

Differs with that of MED, seawater temperature and TDS affect the value of MSF water cost. For any certain TDS, the increase of seawater temperature will increase the water cost. In other hand, for any certain sea water temperature, the increase of TDS will also increase the water cost. The higher the salinity (TDS) of the feed-water, the higher would be the energy consumption of the system and need greater of chemical material dose, so water cost will higher.

For installation of PWR+RO, an increase in TDS will cause increase in the water cost. But, differs to those of MSF, the increase of seawater temperature produces less water cost for any certain value of TDS. The increase of temperature in RO membrane will increase flux (flow of product water) through membrane, so water cost will lower.

An analysis is also performed to see the effect of turbine scheme. Table 6 shows the comparison of water production cost for MED and MSF under back-pressure or extraction scheme.

Table 6. Water Cost for Back-Pressure and Extraction Schemes of MSF and MED Installations

Parameter	Water cost ($/m^3)			
	Back-Pressure		Extraction	
	MED	MSF	MED	MSF
Capital Cost	0.366	0.483	0.348	0.460
O&M cost	0.119	0.114	0.453	0.449
Water Cost	0.885	1.353	1.181	1.570

As is known from Table 6 shows also that the water cost for extraction scheme is greater than that of back-pressure scheme for both MED and MSF. These are caused by the fact that the O&M cost for extraction scheme is higher than that of back-pressure, besides of back-pressure scheme has efficiency (W/P) greater than extraction scheme. Past experience in the co-generation operations leads to conclude that in general backpressure turbine scheme is more economical.

4. CONCLUSION

Having analysed water cost for co-generation installation of PWR+RO, PWR+MED, PWR+MSF by considering some variables, the following conclusion are drawn.

- Water cost of PWR+RO installation is the least. The higher one is that of MSF.
- Interest rate affect the water cost for all installations. An increase in the interest rate of a certain value will increase the water cost produced by PWR+MSF installation more than others.
- Seawater temperature affect differently to water cost of MED, MSF and RO. An increase of seawater temperature increases water cost of MED and MSF, but it decreases the cost of RO.
- An increase of TDS causes water cost increase in MSF and RO. Water cost of MED is not affected by TDS at all.
- Back-pressure turbine scheme produce cheaper water than that of extraction.
- MSF and MED plants produce a high-quality product water with a range of 1.0 – 50 ppm TDS, while RO plants produce product water of 200 – 500 ppm TDS.
- Based on economic aspect and water requirements for reactor coolant system in PWR type, so co-generation of PWR and MED may be a favourable option for being applied in Muria Peninsula.

REFERENCES

[1]. ANONIM, "Comprehensive Assessment of Different Energy Sources", BATAN, 2001-2005, Jakarta, 2005.

[2]. ANONIM, "Peraturan Presiden No. 5 Tahun 2006 tentang Kebijakan Energi Nasional", Jakarta, 2006.
[3]. ANONIM, "Studi Teknologi PLTN PWR, PHWR dan Bahan Bakar DUPIC, Sub Penelitian Studi Teknologi PWR", Teknik Fisika, UGM dan PPEN, BATAN, 2005.
[4]. ANONIM(Federation of Scientific and Technical Association), "Handbook Water and Power Co-Generation Implementation in the Mediterranean Islands and Coastal Areas", Piazzale R. Morandi 2, 20121 Milano (Italy), 2002.
[5]. IAEA, "Safety Aspects of Nuclear Plants Coupled with Seawater Desalination Units", TECDOC-1235, IAEA, Vienna, August 2001.
[6]. IAEA-TEC-DOC-1561, "Economics of Nuclear Desalination: New Development and Site Specific Studies", IAEA July 2007.
[7]. Yuan Zhoua,b, Richard S.J. Tol, "Evaluating The Costs of Desalination and Water Transport", Working Paper FNU-41 Revised, December 9, 2004.
[8]. ANONIM, "Reevaluasi Comprehensive Assessment of Different Energy Sources", BATAN, 2008.
[9]. RAPHAEL SEMIAT, "Desalination: Present and Future, International Water Resources Association", Water International, Volume 25, Number 1, March 2000.